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# A simple method for measuring atmospheric attenuation of light ("meteorological optical range" or visibility) at night

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## 1. Introduction

The standard British instrument for measuring visibility at night is the "Night Visibility Meter (Mk.II)". This is basically the instrument devised by Gold(1939) with modifications described by Bibby (1947). The more elaborate "Photoelectric Visibility Meter (Mk.II)" is used at a few stations to give continuous records, and the very simple and direct method of counting the number of lights visible is used on the runways of important airports to give precise local estimates of "runway visual range". The method to be described is put forward as an alternative to the Gold meter method; it would not give the specialized information required for runway visual range reports or the continuous records provided by the photoelectric meter. Its great advantage over the Gold meter is that it uses a "matching" rather than an "extinction" method for estimating the illumination from a distant lamp.

## 2. Outline of method

The method requires two lights and a small convex mirror. One light is set up at a distance comparable with the visibilities to be measured and is viewed directly. The other light is carried on the observer's head and is viewed by reflection in the mirror, which is fixed on a stand at eye level a few yards from the observer (see Fig. 1). The observer moves until the distant light comes nearly into line with the reflection of his own light and then moves backwards or forwards until the two lights appear equally bright. The exact theory is given in the appendix, but it is easy to see that if the distance from observer to mirror is small compared with that of the distant light and large compared with the focal length of the mirror, then the apparent intensity of the distant light will vary little as the observer moves, while that of the reflection will vary roughly inversely as the fourth power of his distance from the mirror. The distance from observer to mirror thus gives a measure of the apparent intensity of the distant lamp, and if the measurement is made first on a clear night then on one of poor visibility, the ratio of the matching distances in the two cases is a measure of the attenuation of the rays from the distant lamp, independent of the relative power of the two lamps and of the reflectivity of the mirror, provided these remain constant. The distance of the distant light being known, the attenuation per unit distance can be calculated and hence, by well-known formulae, the "visibility" or "meteorological optical range".

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## 3. Practical trial

The method has been tried at Kew Observatory on a number of occasions in the past two winters. A street lamp of about 100 c.p. 700 m away was used as the distant light and a 60 watt bulb was carried by the observer on simple headgear. The convex mirror was back-silvered, of "school" quality, 5 cm aperture and 10 cm focal length. In clear conditions matching occurred at about 5 m from the mirror, so that by walking backwards to 20 m from the mirror the observer could reduce the reflected intensity about 250 times. The mirror was supported on a single thin pillar so that by moving his head the observer could view the distant light either to left or right of the reflected one. Distance from the mirror was measured by reference to pegs in the ground at 1 m intervals, the observer's eyes being assumed to be vertically above his toes. Readings were estimated to 0.1 m.

Eight different observers tried the method. Most had little confidence in their matching ability at first, but were soon able to obtain reproducible readings (the accuracy is assessed quantitatively in the next section). One observer (with poor eyesight) obtained very discordant results, which were not used. The main difficulty in matching was caused by slight differences in the appearance of the two lights. The reflected image always appeared effectively a point source, but the distant street lamp sometimes seemed to have a perceptible angular size (the bulb of the lamp was small enough to appear as a point source, but parts of the reflector and cover glass may have reflected light to the observer and increased the size of the source). In hazy weather the distant lamp sometimes appeared considerably redder than the near one. The consequent difficulty in matching can easily be overcome by viewing both lights through a roughly monochromatic filter, but in practice this seemed unnecessary because it was found surprisingly easy to ignore the colour difference and match the lights for brightness alone.

## 4. Accuracy

Systematic errors may occur through ageing of one or other of the lamps, fluctuations of one supply voltage (ideally the two lamps would be run from the same supply) or deterioration of the mirror. These errors have not been investigated experimentally, but, with reasonable precautions, they seem likely to be small in comparison with the random errors of the matching procedure. These random errors were studied in two series of trials. In the first trials one observer matched the reflection to the distant light five or more times in quick succession, noting the matching distance (x) each time. This was repeated on many different nights, in visibilities ranging from twenty miles to less than half a mile. In the second series of trials two observers made the observations in succession, each usually taking three readings. In both series of trials Gold meter observations, on the same distant light, were made just before or after the mirror observations.

From the first series of trials we can estimate the variability of readings by a single observer. This is best expressed in terms of the variability of the attenuation represented by the readings. The difference in attenuation corresponding to readings x and $\bar{x}$ is $(x/\bar{x})^4$ or $40 \log_{10}(x/\bar{x})$ decibels. The departure of each individual reading (x) from the mean of its set ($\bar{x}$) was expressed in decibels in this way and a histogram of the departures is shown in Fig. 2(a). The standard deviation of individual observations (the square root of the average variance) is 0.4 db.

The Gold meter method measures attenuation-differences directly in "nebules", and from their respective definitions, 1 nebule = 0.3 decibels. The departure of each reading from the mean of its set was found and the departures are plotted in Fig. 2(b). The standard deviation is 1.1 db.

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It is clear that, at any rate with this observer, the mirror method gives much smaller random errors than the Gold meter. The second series of trials measured the variability of readings between different observers. For each occasion the difference in the readings (usually the means of three observations) by the two observers was expressed in decibels, as before, and the standard deviation of these differences was calculated. With the mirror method the mean difference between any two observers should be zero, so the standard deviation from zero was calculated, but with the Gold meter there will be a difference between observers with different eyesight (a difference that can be allowed for, if constant, by calibration of individual observers) so the standard deviation from the mean was calculated. Only one pair of observers made enough observations to give a reliable mean difference of Gold meter readings, so the estimate of standard deviation of Gold meter observations is restricted to this pair. The results were:

Standard deviation of differences between
Gold meter observations by one pair of observers = 3.8 db
(eight pairs of observations).

Standard deviation of differences between
mirror observations by the same pair of observers = 1.4 db
(eight pairs of observations).

Standard deviation of differences between
mirror observations by various other pairs of observers = 1.3 db
(eight pairs of observations).

These deviations are about three times as large as would be expected from the scatter of readings obtained by a single observer on any one occasion, as measured in the first series of trials. Presumably changes in the criteria for matching (with the mirror method) and extinction (with the Gold meter method) occur from one occasion to another and increase the difference between the results of two observers when observations are made on a number of different occasions. This might be expected with the Gold meter because the sensitivity of the eye is known to vary with health, fatigue, diet and so forth, but it is rather surprising to find it occurring with the matching process. It may be that the changes in colour and shape of the distant lamp noted earlier affect different observers differently and that their elimination would improve the agreement between observers. Even without this possible improvement, however, the mirror method clearly gives much better agreement between different observers than the Gold meter method, with the additional advantage that no individual calibration is needed. The possibility that the rather large standard deviation of differences between Gold meter observations was caused by inability of one or other of the observers to use the instrument properly was checked by finding the standard deviations of the differences between each observer's mirror and Gold meter observations. These were 3.1 and 3.9 db, implying no great difference between the observers. (They may, of course, both have been insufficiently practised in the use of the instrument, but this seems unlikely.)

The relation between Gold meter and mirror estimates of attenuation is shown in Fig. 3. The points show considerable scatter, as would be expected from the figures given above, but the general agreement between the two methods seems satisfactory.

Accuracy has been discussed so far in terms of the measurement of attenuation. If the result of the measurement is expressed as a visibility (V) the accuracy will depend on the ratio of the visibility to the path length over which it is measured (i.e., the distance (y) of the distant light), as well as on the accuracy of the actual measurement. If there is an error of B decibels in the attenuation it can be shown that the corresponding percentage error in visibility is

$$\frac{100 \log_{10} e}{3.91 \times 10} \frac{V}{y} B = 5.75 \frac{V}{y} B.$$

The standard deviation of 1.4 db found between two observers' estimates by the mirror method would thus correspond to a deviation of about 32 per cent. in visibility, if the visibility was four times the path length. For smaller visibilities the accuracy would be greater, but the method becomes unusable when the visibility is much smaller than the path length, because the distant light is invisible. A set of lights at different distances would therefore be required to measure a wide range of visibilities with tolerable accuracy.

## 5. Discussion

The mirror method was designed as a simple way of using the matching principle to compare two point sources. It has been shown that it is simple to use and gives reasonably accurate results. The reproducibility of readings on a single occasion, in fact, is as good as that reported by Collier (1938) for the laboratory comparison of point sources. The main practical disadvantage of the mirror method is that it requires a 20-25 yd pathway for the observer, level and in line with the distant light, and is therefore almost inevitably an outdoor measurement, which may be difficult and uncomfortable (and so, probably, inaccurate) in bad weather. The importance of this disadvantage and the general value and practicability of the method could only be found by several months' trial in routine working conditions. A hand-held "artificial star" type of instrument would preserve the advantage of the matching principle and might prove more convenient in use, though it would probably be more expensive.

## References


| | | |
|---|---|---|
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## Appendix. Calculation of matching distance

The system is sketched in Fig. 1. The observer's eye, E, and the light he carries, P, (of candlepower P) are at a distance x from the surface of the mirror M, of semi-aperture $a$, radius of curvature r and reflectivity $\rho$. A light of candlepower Q is at a distance $y$ from the mirror. We assume the attenuation coefficient for visible light, $\sigma$, to be uniform between P and Q. Then illumination produced by Q at E,

$$I_Q = \frac{Q}{(x+y)^2} e^{-\sigma(x+y)} \quad \text{lumens/unit area}$$

Also, light flux from P falling on M is

$$L = \frac{\pi a^2 P}{x^2} e^{-\sigma x} \quad \text{lumens}$$

This flux forms an image at a distance $z$ behind M, given by

$$\frac{1}{z} = \frac{2}{r} - \frac{1}{x}$$
$$\simeq \frac{2}{r} \quad \text{if } x \gg r$$

and the reflected flux is therefore distributed over a solid angle of

$$\frac{\pi a^2}{z^2} = \frac{4\pi a^2}{r^2} \text{ steradians} \quad (a \ll z)$$

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The illumination (flux per unit area) at E due to the light from P reflected in M is thus

$$I_P = \frac{\pi a^2 P}{x^2} e^{-\sigma x} \frac{r^2}{4\pi a^2 x^2} \rho e^{-\sigma x}$$

$$= \frac{P r^2 \rho}{4 x^4} e^{-2\sigma x} \quad \text{lumens/unit area}$$

Matching of Q to the image of P in M occurs when

$$I_P = I_Q$$

$$\text{or } e^{-\sigma(y-x)} = \frac{1}{x^4} \frac{P r^2 \rho (x+y)^2}{4Q} \qquad (1)$$

In most applications $x \ll y$ and we can write, for matching,

$$e^{-\sigma y} = \frac{1}{x^4} \frac{P r^2 \rho y^2}{4Q}$$

If $x_o$ is the matching distance in very clear conditions ( $\sigma = 0$) we have

$$x_o^4 = \frac{P r^2 \rho y^2}{4Q}$$

and the equation for matching in other conditions is simply

$$e^{-\sigma y} = \left(\frac{x_o}{x}\right)^4 \qquad (2)$$

$$\sigma = \frac{4}{y} \log_e \frac{x}{x_o}$$

The visibility, V, is given by Koschmieder's equation

$$V = \frac{3.91}{\sigma}$$

so that we can write, with very little error,

$$V = \frac{y}{\log_e (x/x_o)} \qquad (3)$$

To show the relation between V and x the table below has been calculated for a system with the following values:

P = 50 c.p. $\rho = 0.70$ r = 20 cm

Q = 10 c.p. at 100 m, 50 c.p. at 400 m and 250 c.p. at 1600 m

(i.e., using a set of three distant lights to cover a range of visibilities). Table 1 has been calculated from the more exact equation (1); a few values calculated (with the same value of $x_o$) from the approximate equation (2) are given in brackets.



/Table 1

Table 1

Visibility (metres) for matching distance x

| x metres | y = 100 m | y = 400 m | y = 1600 m |
|---|---|---|---|
| 4.4 | ∞ | - | - |
| 5.8 | - | ∞ | - |
| 7.7 | - | - | ∞ |
| 5 | 770 | - | - |
| 6 | 308 | 9,900 | - |
| 7 | 204 | 2,020 | - |
| 8 | 156 | 1,180 | 41,000 |
| 9 | 129 | 870 | 10,500 |
| 10 | 111 (122) | 700 (712) | 5,970 (5,970) |
| 12 | 89 | 524 | 3,510 |
| 14 | 76 | 430 | 2,600 |
| 16 | 66 | 372 | 2,120 |
| 18 | 60 | 333 | 1,830 |
| 20 | 54 (66) | 303 (315) | 1,630 (1,640) |
| 22 | 50 | 281 | 1,480 |
| 24 | 47 | 261 | 1,370 |

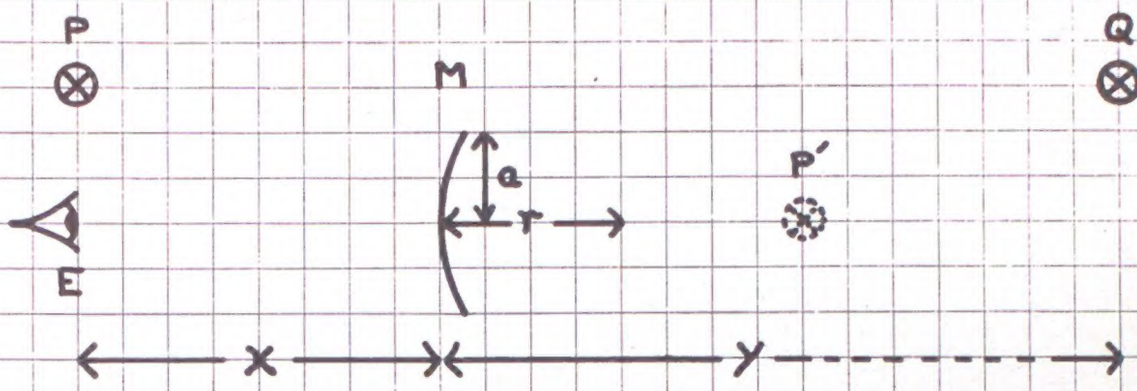


Fig. 1 Arrangement of lights and mirror ( not to scale ) .

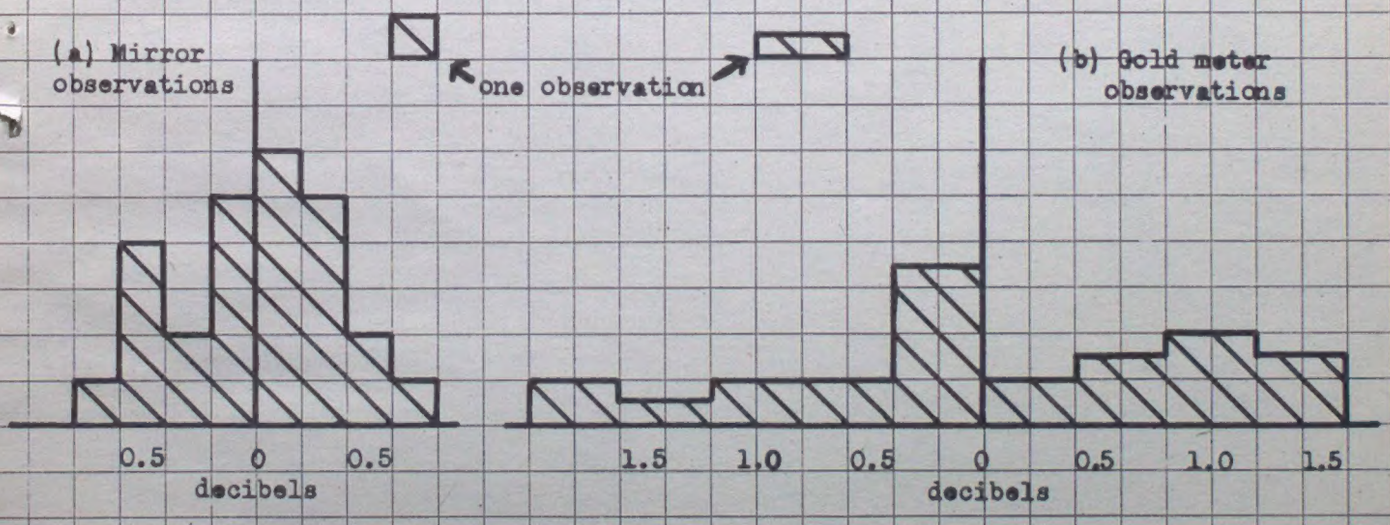


Fig. 2 Departures of individual observations from mean of their set.

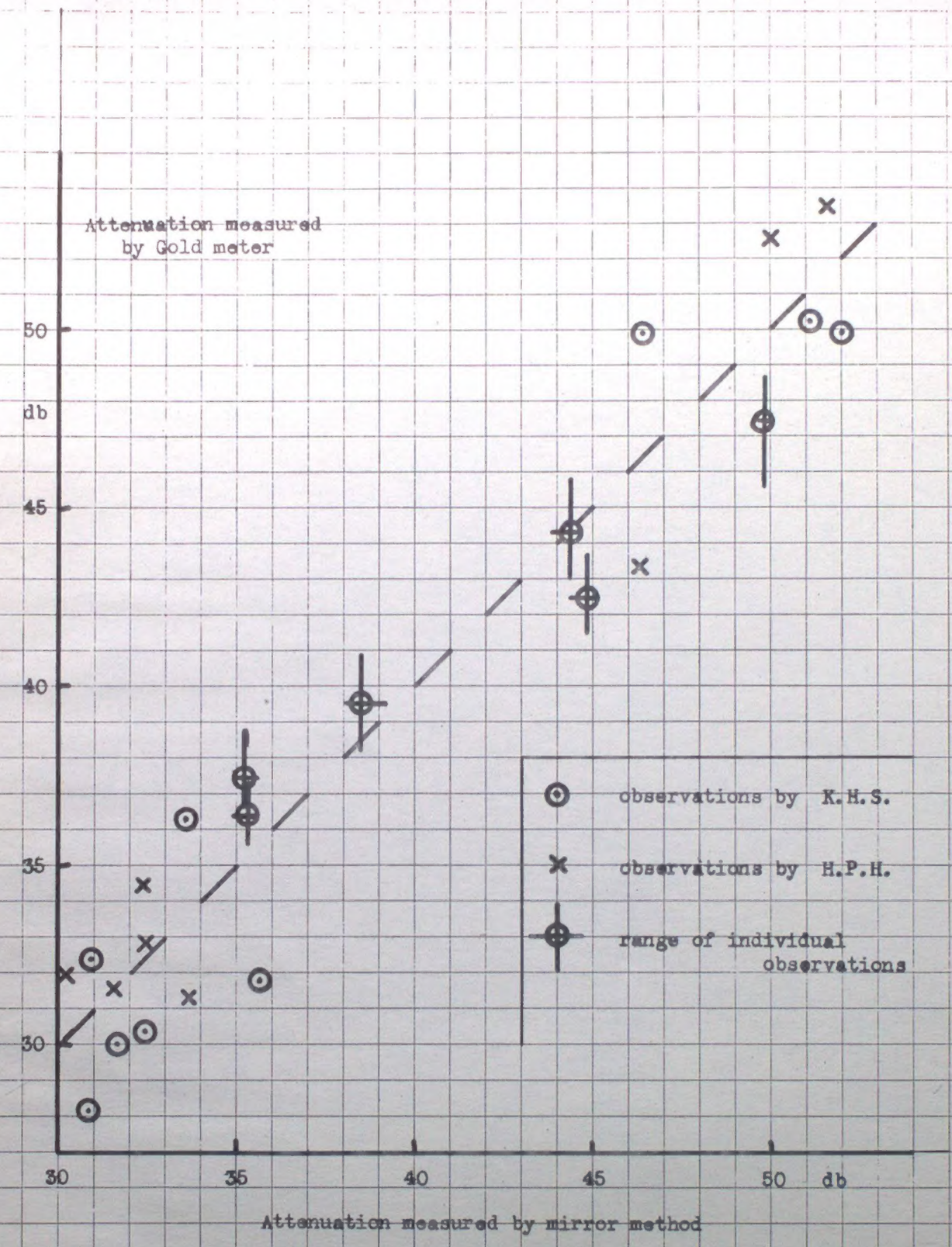


Fig. 3 Comparison of mirror and Gold meter observations ( arbitrary zero )